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SUBSONIC AND TRANSONIC AIRFOIL DESIGN APPLYING NUMERICAL OPTIMIZATION TECHNIQUES

The specific design of airfoils is one of the classical tasks of aerodynamics. Since the airfoil characteristics are directly dependent on the inviscid pressure distribution the application of inverse calculation methods is obvious. The numerical airfoil optimization offers an alternative to the inverse design and attracts increasing interest. With this approach an automated search for an optimal solution with respect to a user-specified objective function is performed. An overview about recent results on subsonic and transonic airfoil optimizations will be given.

The objective of the subsonic airfoil optimizations was to design natural laminar flow airfoils which show minimized drag for a specified range of the Reynolds number and the lift coefficient.

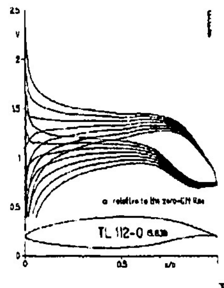

Fig.1

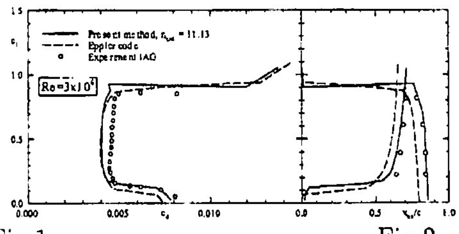

Fig.2

To this purpose an efficient aerodynamic model was coupled with a hybrid optimizer [2]. Contrary to the usual approach the airfoil is not parameterized by geometric shape functions. Instead, the inverse conformal mapping procedure according to Eppler [1] was applied to generate the airfoil shape and to evaluate the inviscid velocity distribution. The input parameters of this method are being used as design variables of the optimization process. The potential flow method is coupled with an improved intergal boundary-layer procedure and an e^n database method for transition prediction. A large number of 34 design variables was considered in order to enable a detailed representation of the airfoil pressure distribution. One optimization result is depicted in Figs. 1 and 2. The objective was to minimize the average drag coefficient for angles of attack $\alpha_{design} = [2°, 3°, ..., 8°]$ relative to the zero-lift line [5]. Two Reynolds numbers were considered, namely $Re_{design} = 3 \cdot 10^6$ and $9 \cdot 10^6$. In order to enhance the stall characteristics, the curvature of the lift curve was limited at off-design conditions. Wind-tunnel tests for the optimized airfoil showed very low drag coefficients inside the laminar bucket which exactly coincides with the design lift region, compare Fig. 2. Besides the design of minimum drag airfoil sections the optimization method has been applied to derive the shape of airfoils from prescribed drag polars or to design airfoils with minimized trailing-edge noise [3, 4].

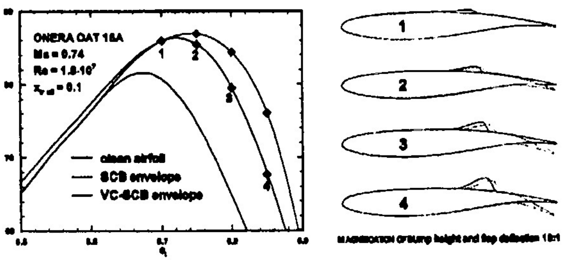

Fig.3

For the transonic flow regime numerical optimization techniques were applied to investigate the drag reduction potential of adaptive mechanisms for transonic airfoils at off-design conditions. Above the design Mach number transonic airfoils show a steep drag rise caused by shock waves and boundary-layer separation on the suction side. For specific onset flow conditions the wave drag can be reduced by an adaption of the airfoil camber plus local shape modifications. A feasible approach for the shape modification is the introduction of a Shock Control Bump (SCB) in the vicinity of the shock, whereas the camber can be altered by means of a trailing-edge flap. In order to maximize the aerodynamic efficiency over a broad c_l or $Mach$-range, the shape and position of a SCB as well as the flap setting has to be adapted permanently. To quantify the gain, different bump shapes were designed by means of numerical optimization. The optimization tool consists of a coupled Euler boundary-layer code in combination with a hybrid optimizer. Besides the bump designs, the gain due to an optimization of the flap deflection angle and finally the effect of a combined SCB plus flap optimization was investigated [6, 7]. The results show a dramatic improvement over the whole off-design regime of the basic airfoil, especially for the combination of the adaptive mechanisms, see Fig. 3.

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